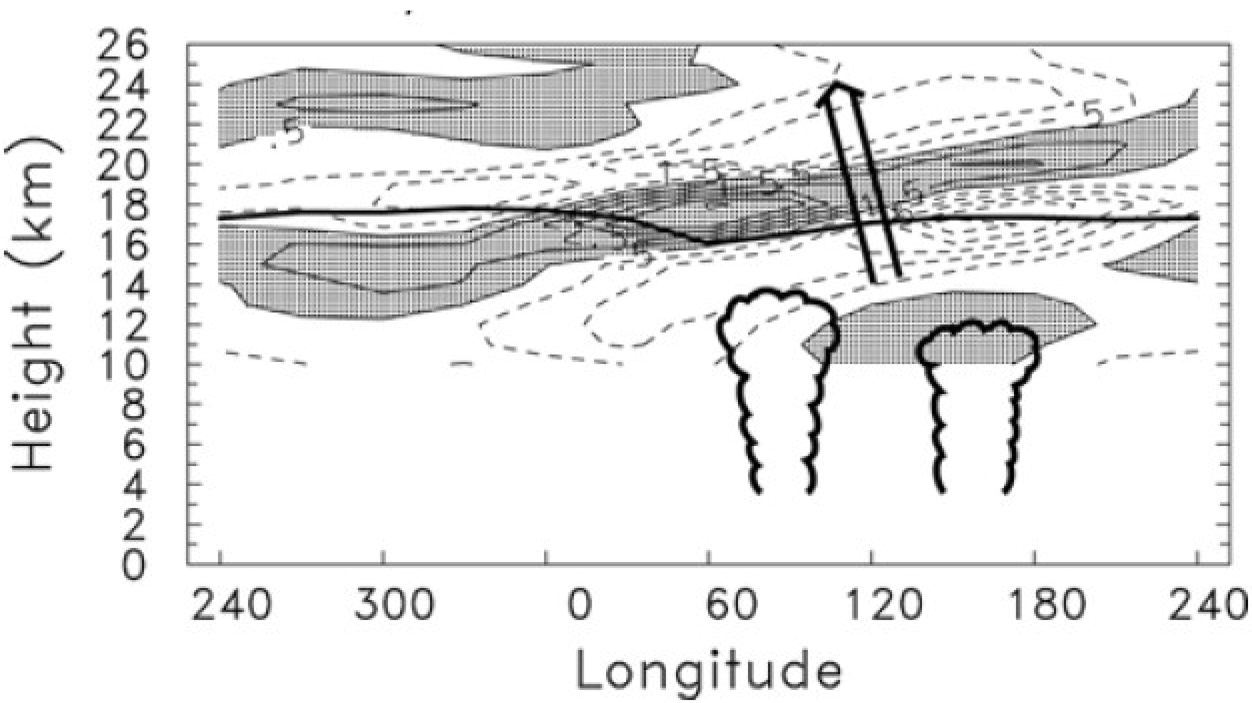
Equatorial Waves and Influences in the UTLS Inferred from Asynoptic Fourier Analysis of HIRDLS Temperatures

M. Joan Alexander, Dave Ortland, and Jung-Hee Ryu
NorthWest Research Associates

• Alexander, M. J. and D. A. Ortland, 2010: Equatorial waves in High Resolution Dynamics Limb Sounder (HIRDLS) data, *J. Geophys. Res.*, (accepted).

• Ryu, J.-H., M. J. Alexander, and D. A. Ortland, 2010: Equatorial waves in the upper troposphere and lower stratosphere forced by latent heating estimated from TRMM rain rates, *J. Atmos. Sci.*, (submitted).

Overview of the Work: Tropical Waves Generated by Convection



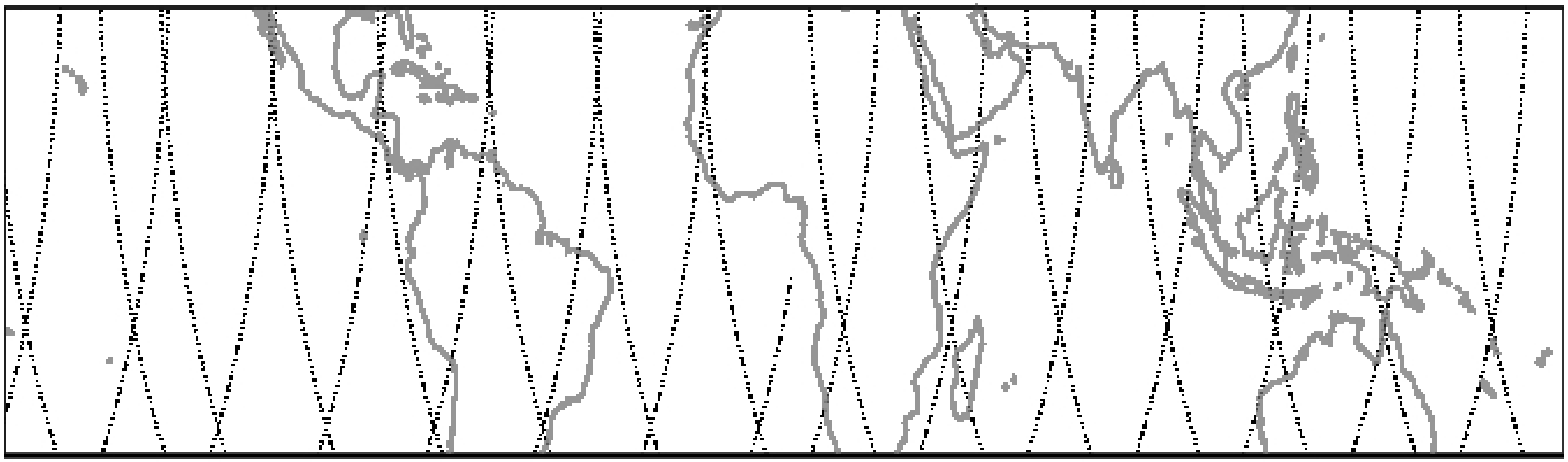
Randel & Wu '06: Cartoon of tropical convection and Kelvin Wave temperature anomalies fromGPS.

• Here we examine tropical waves as seen in HIRDLS temperature data.

• We have also developed numerical models of tropical waves forced by latent heating (Ortland et al., talk this morning) and we are validating these models with the HIRDLS observations.

Advantage of HIRDLS Sampling: Comparisons SABER & GPS

Example day of HIRDLS data: Profile locations

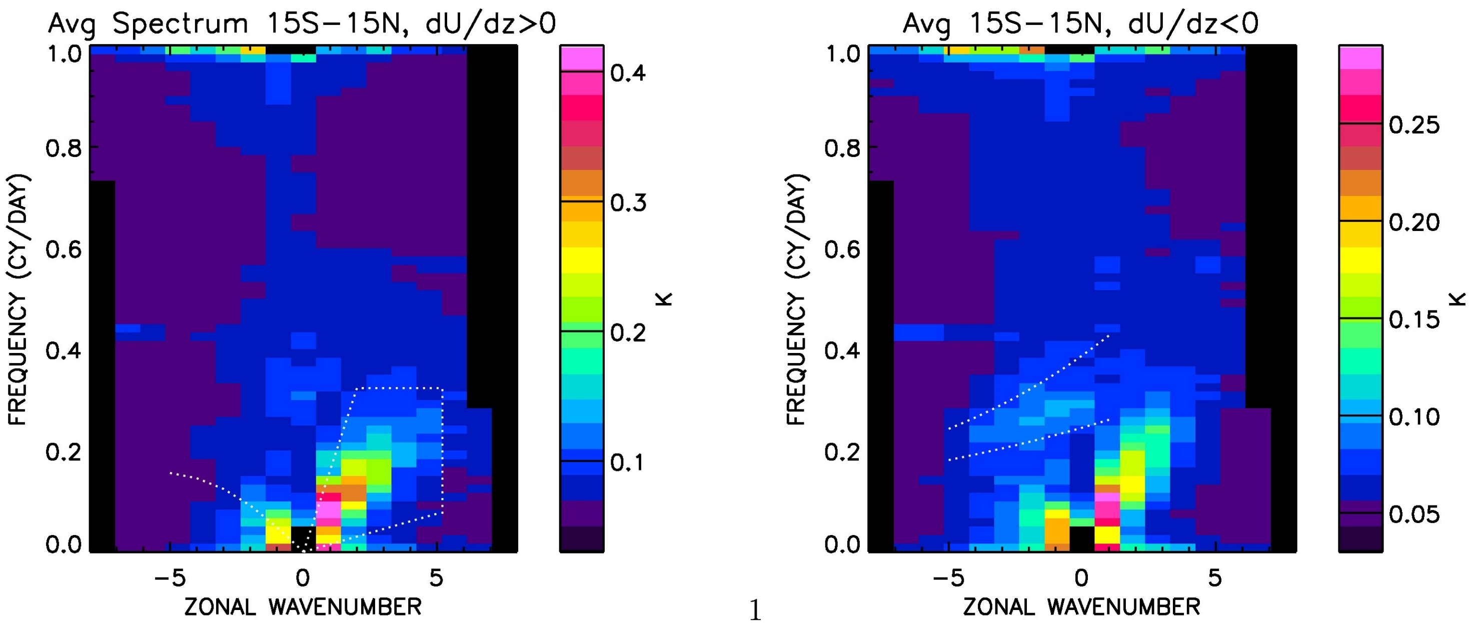


	HIRDLS	SABER	GPS
Vertical Resolution	1.2 km	~2-2.5km	1 km
Zonal resolution	wn ~ 7	wn ~ 7	wn<8?
10S-10N profiles/day	~650	~200	~200*

* Champ + COSMIC

- **HIRDLS has vertical resolution (similar to GPS), but has very high latitudinal resolution ~1^{o}. giving excellent sampling for the study of equatorial wave modes at tropical latitudes.**

Asynoptic Fourier Transform of HIRDLS Temperatures



Use Salby [1982] method to derive the equatorial wave spectrum from HIRDLS temperatures

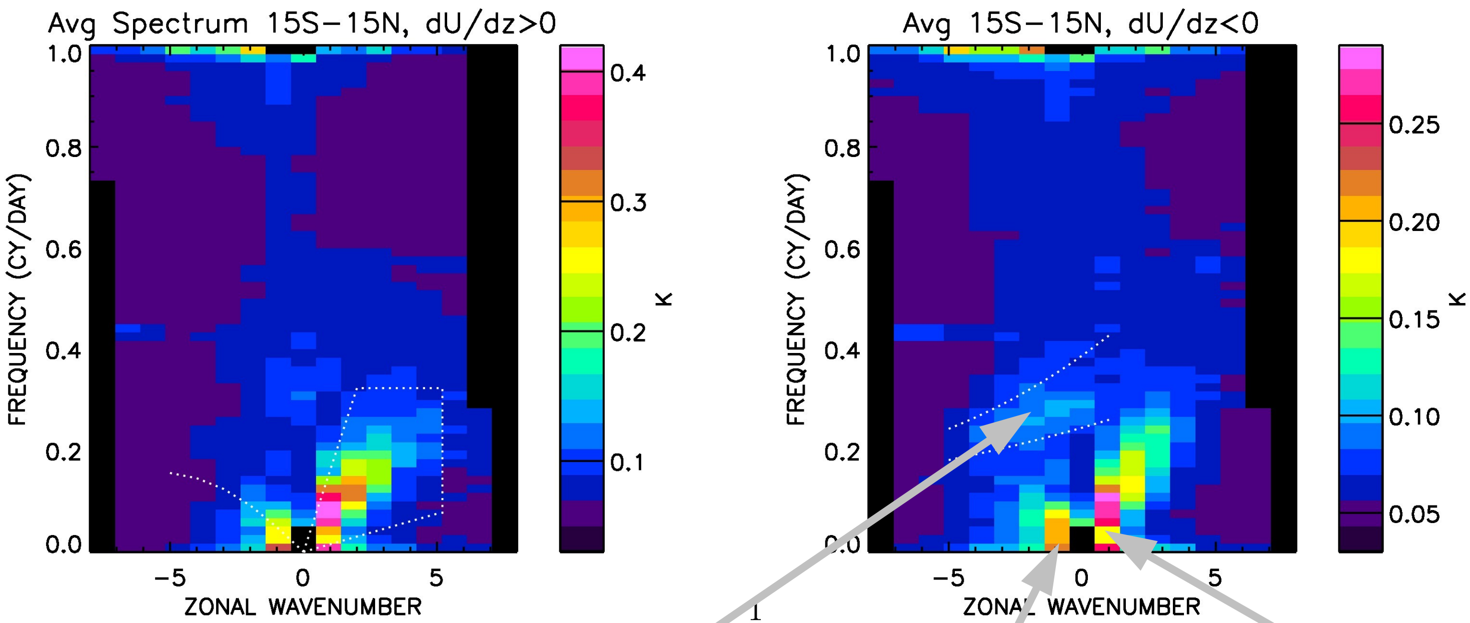
Wavenumber-frequency spectrum of HIRDLS temperatures at z=15-32 km averaged over 15^{o}S-15^{o}N and 3 years Jan 2005 - Jan 2008.

- Zonal wavenumbers up to *k*=8 depending on frequency
- Wave periods ranging from ~1-60d (from 60-day data series)

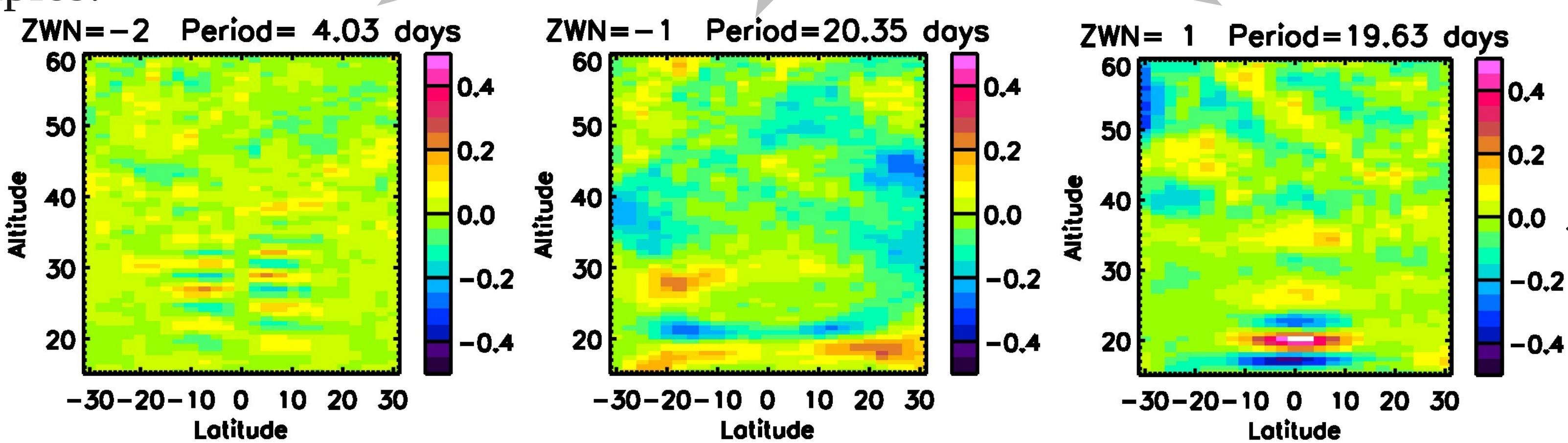
Left: Eastward wind shear with U < 8 m/s
Right: Westward shear with U > -20 m/s

Dotted curves show equatorial wave dispersion curves.

Asynoptic Fourier Transform of HIRDLS Temperatures



Examples:



Mixed Rossby-Gravity

Equatorial Rossby

Kelvin

Asynoptic Fourier Transform of HIRDLS Temperatures

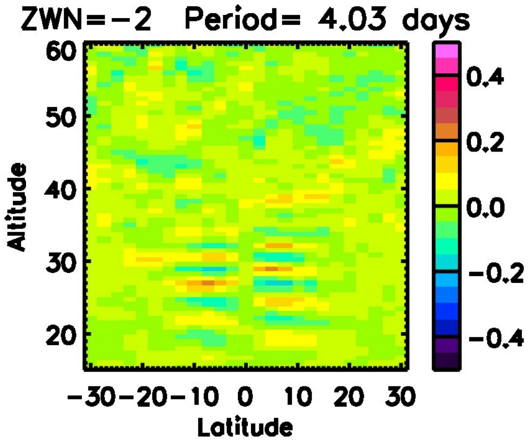
- **Note that each point in latitude and height is the result of a completely independent spectral analysis.**

- **The equatorially-trapped symmetric or anti-symmetric structure with oscillating phase with height is a clear confirmation of the interpretation of these signals.**

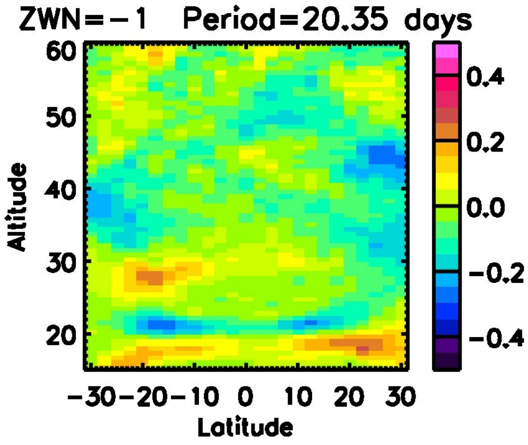
- **Wavelengths as short as 4 km are clearly observed.**

HIRDLS resolves wave structure in fine detail in both latitude and height

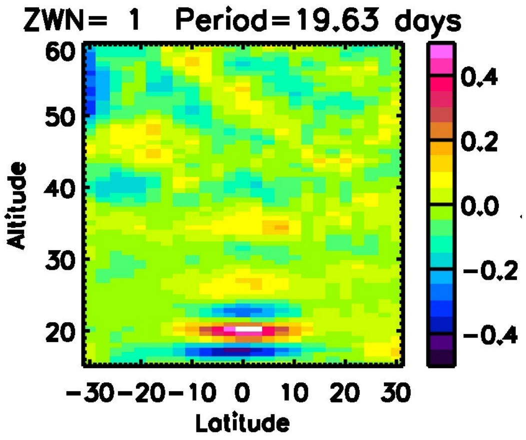
Examples:



Mixed Rossby-Gravity



Equatorial Rossby

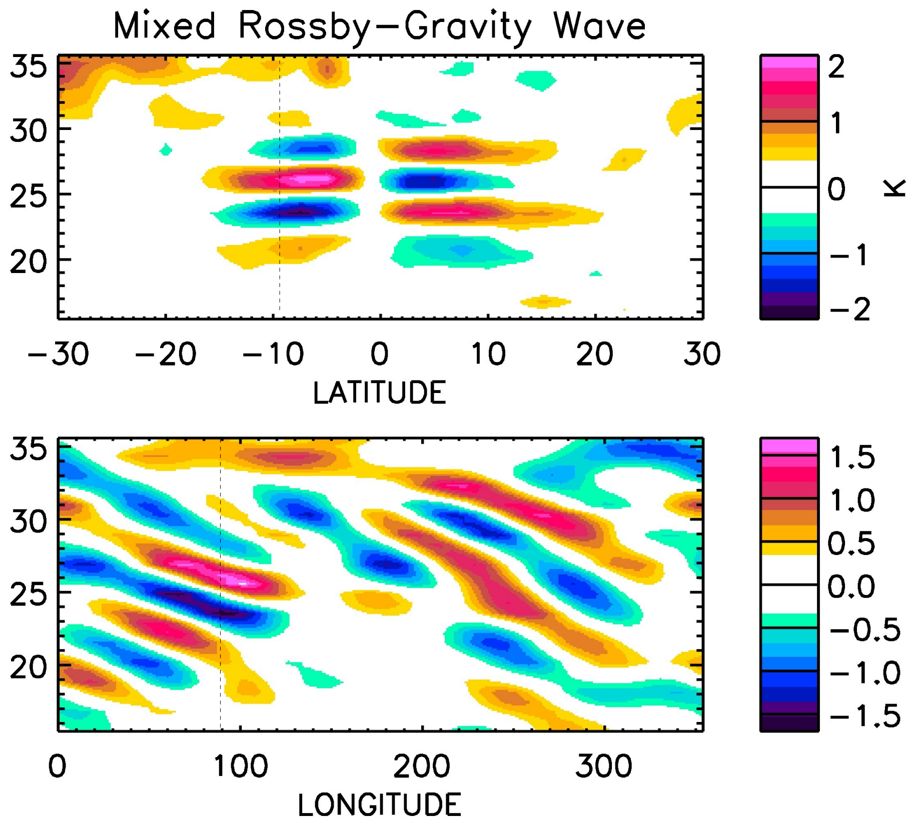


Kelvin

Mixed-Rossby Gravity and Equatorial Rossby Wave Events

2006

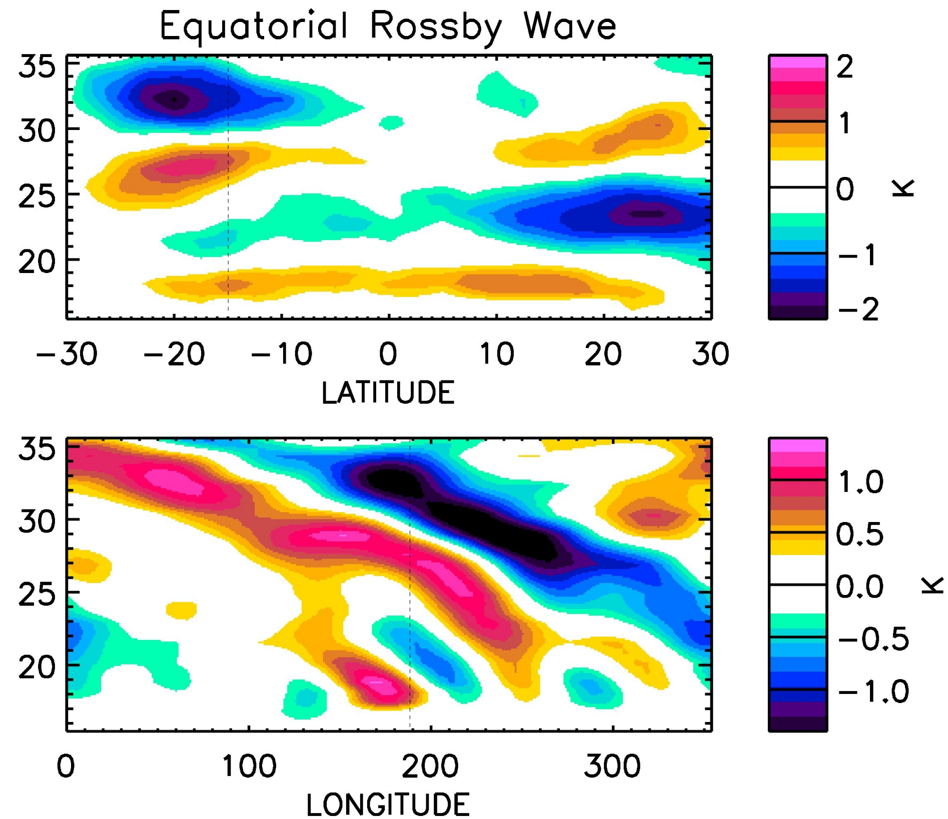
day 305



Filter: k=-5 to 0, λ_Z=4-10 km

Although the mixed Rossby-gravity waves appear weak in the averaged spectrum, they are quite prominent at times.

day 354

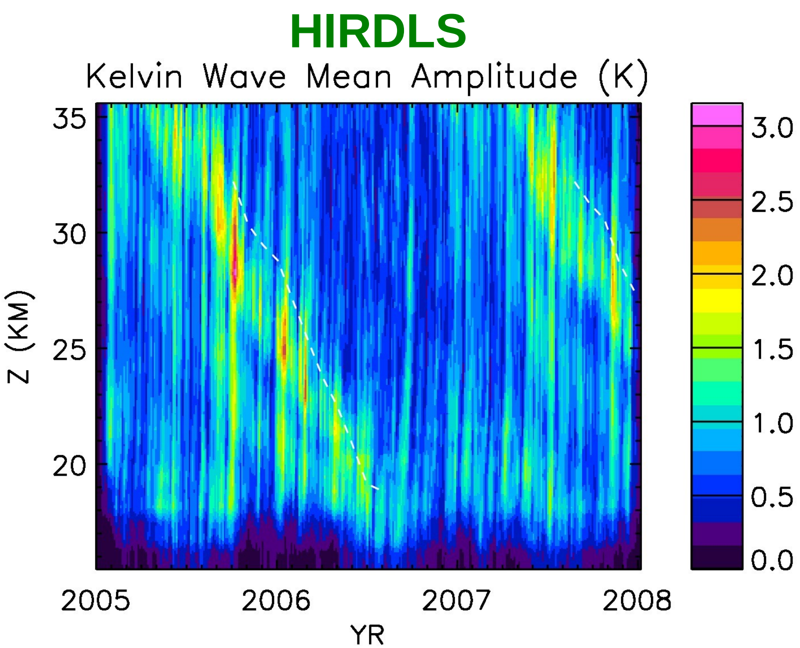


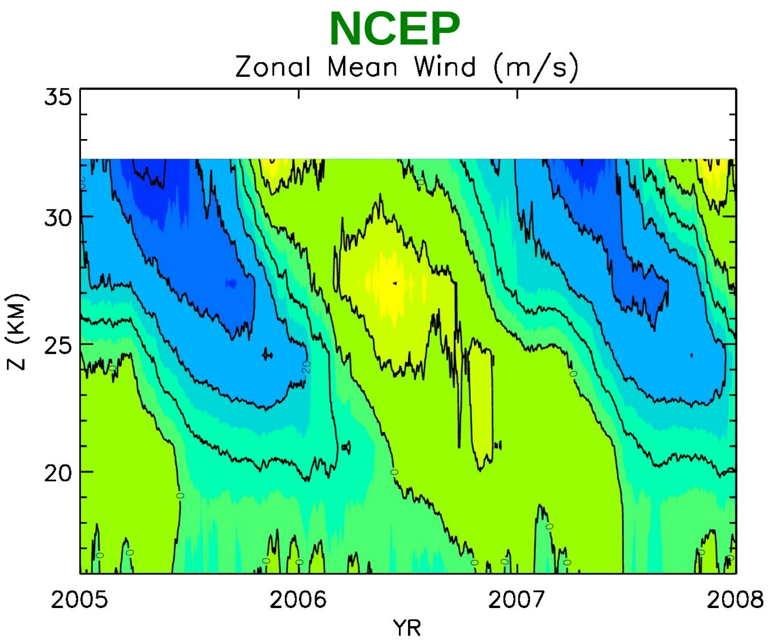
Filter: k=-5 to -1, λ_Z<20 km, Periods>32d

This example displays clear n=1 symmetric equatorial Rossby wave structure with k~2-4.

Kelvin Waves

Filter: k=1-5, ω=.05-.32 cy/d, c=7-75 m/s

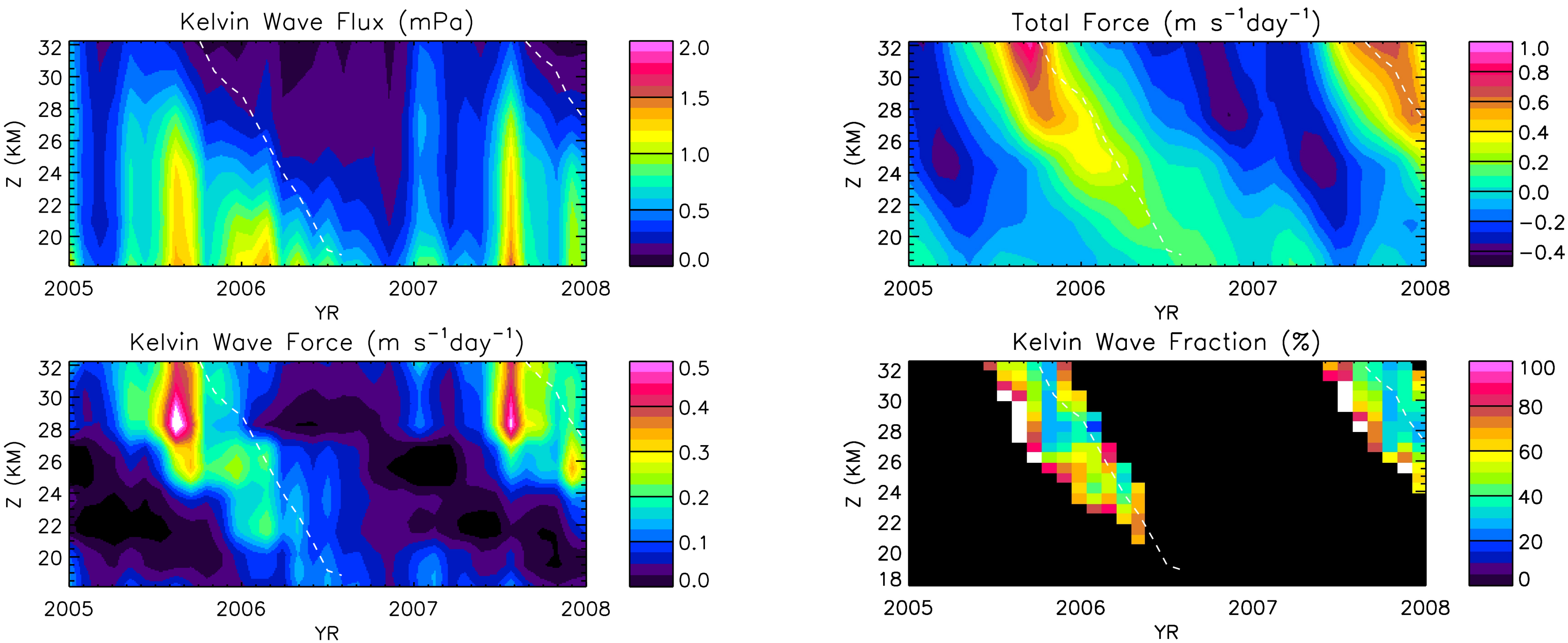




- 2005-2008 time-height record of daily Kelvin wave amplitudes averaged in longitude at the equator.
- The amplitudes maximize below and near the zero wind line of descending westerly winds in the QBO.

Kelvin Waves

- *Momentum flux* estimated from the spectral analysis $T'(k,\omega)$ and the dispersion relation $m=Nk/(\omega-Uk)$
- *Force* on the mean flow = $-\rho^{-1}d(flux)/dz$



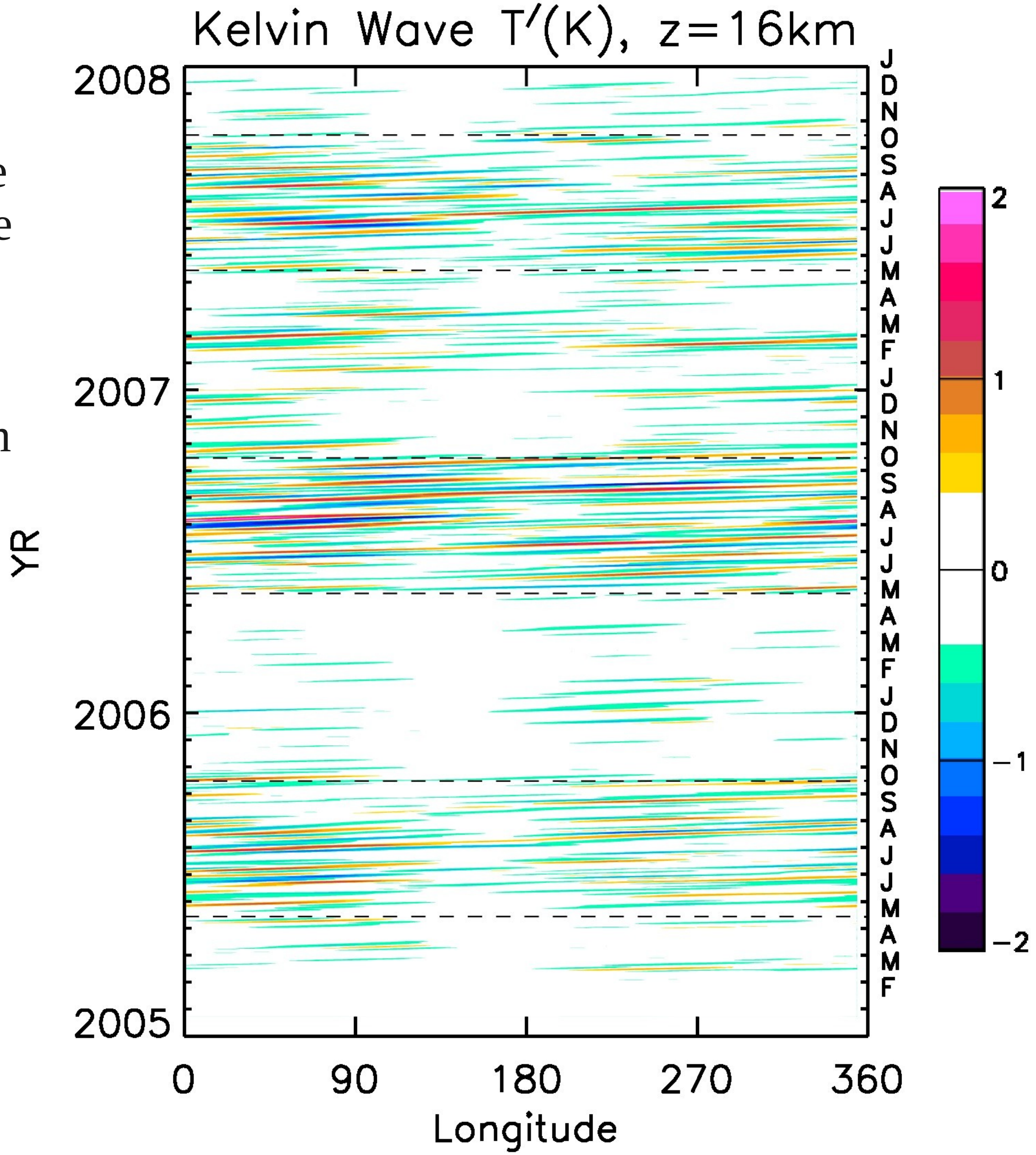
- Total force = wind acceleration plus vertical advection $dU/dt + wdU/dz$
- Fraction = *(Kelvin wave force)/(total force)*100%*
- Average fraction ~ *47%* (where Total > 0.2 m/s/d)

Kelvin Waves

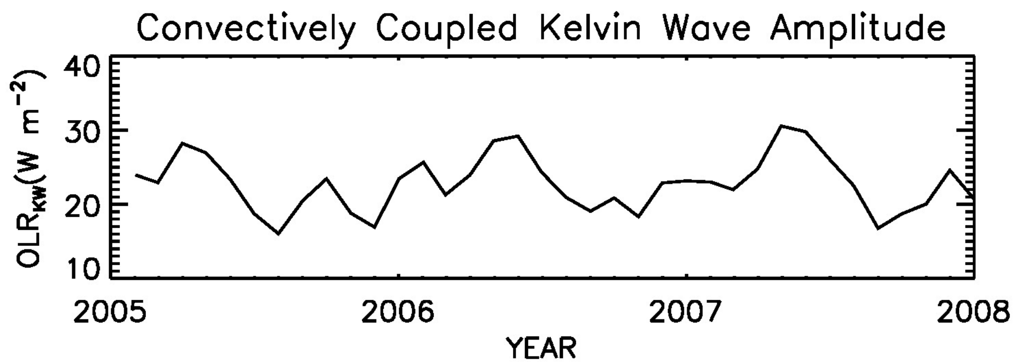
• Longitude-time Kelvin wave perturbations at 16 km altitude in the tropopause transition layer derived from HIRDLS

• Annual cycle with maximum amplitudes in boreal summer May-October

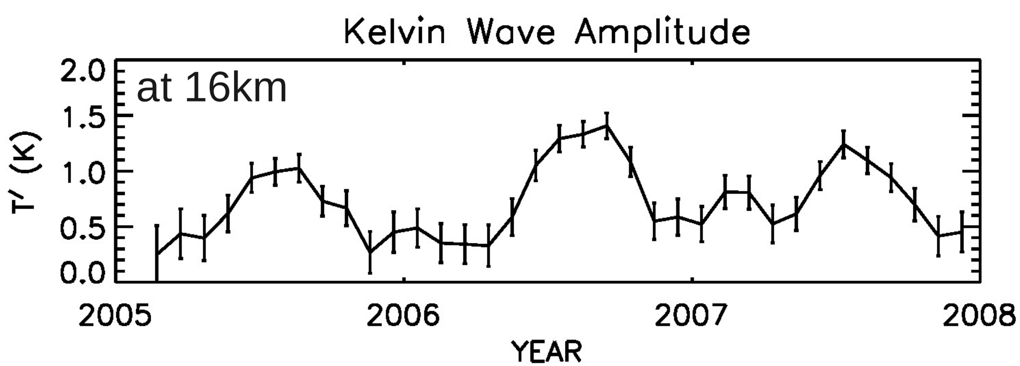
The annual cycle is apparent up to 18 km altitude. Above this, a QBO cycle dominates.



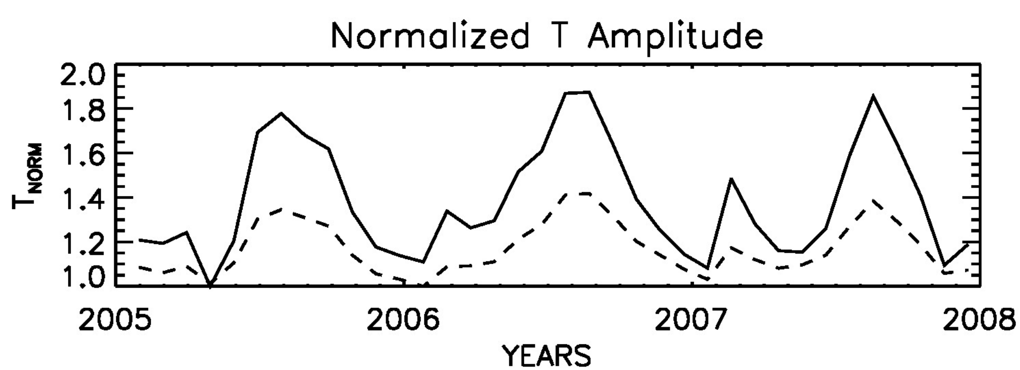
Kelvin Waves



Kelvin wave signal in OLR shows convectively coupled Kelvin wave amplitude that peaks in Mar-Apr.



TTL Kelvin waves peak May-Oct. Errors increase 25-50% in boreal winter when cirrus cloud occurrences cause loss of HIRDLS temperature measurements.

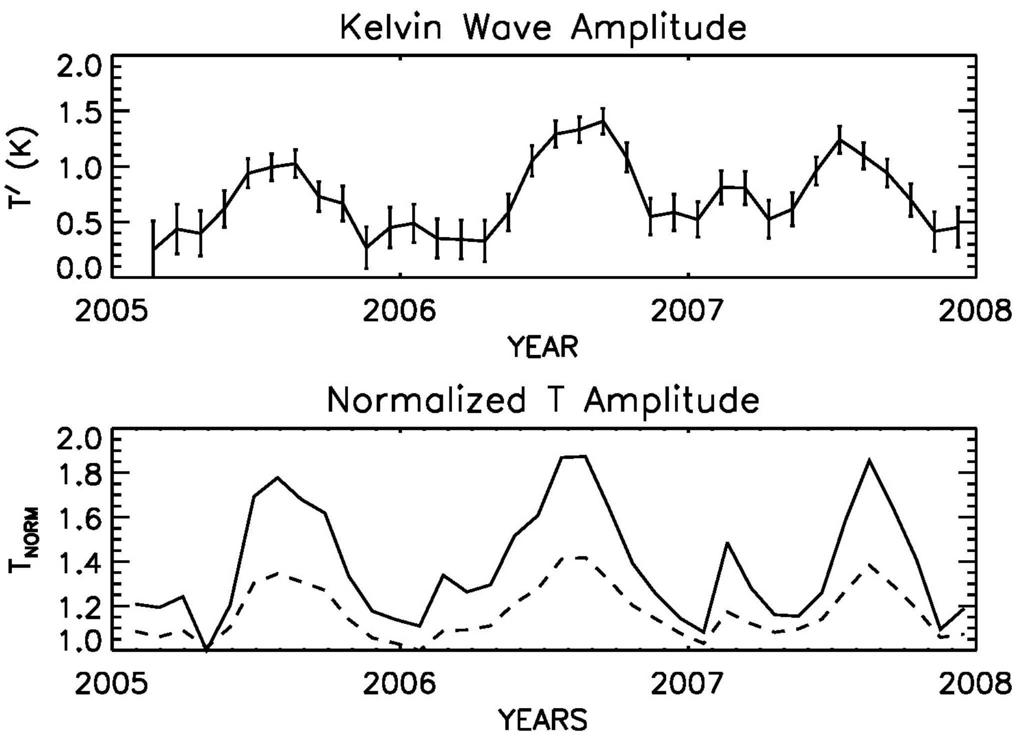


The annual cycle can be explained as as the potential energy response to changes in the background winds and static stability. At left are theoretical *T'* variations assuming constant wave action.

Kelvin Waves

Assuming constant wave action $A = (Momentum\ flux)/(k\ c_{gz})$ compute the sensitivity of the temperature amplitude to the background wind and stability:

$$T' \;\; \alpha \;\; |c-U|^{1/2} N$$



c = 10 m/s

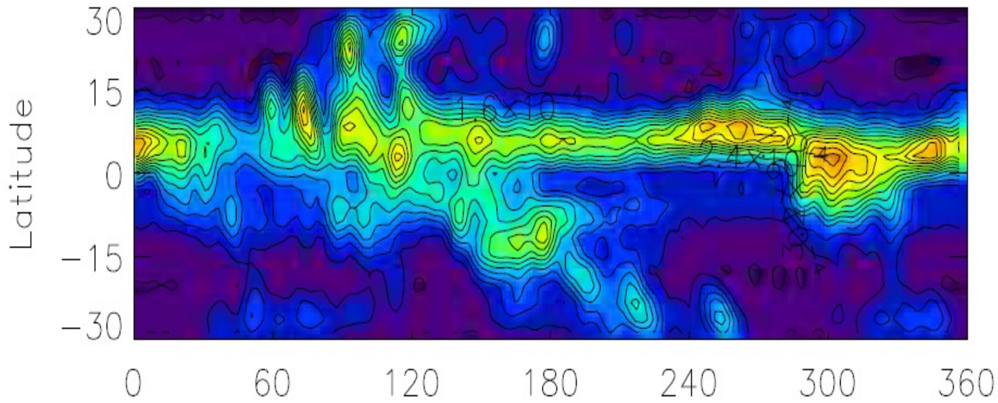
c = 25 m/s

T' normalized to show range of variation illustrates how this effect may explain the annual cycle in Kelvin wave amplitudes

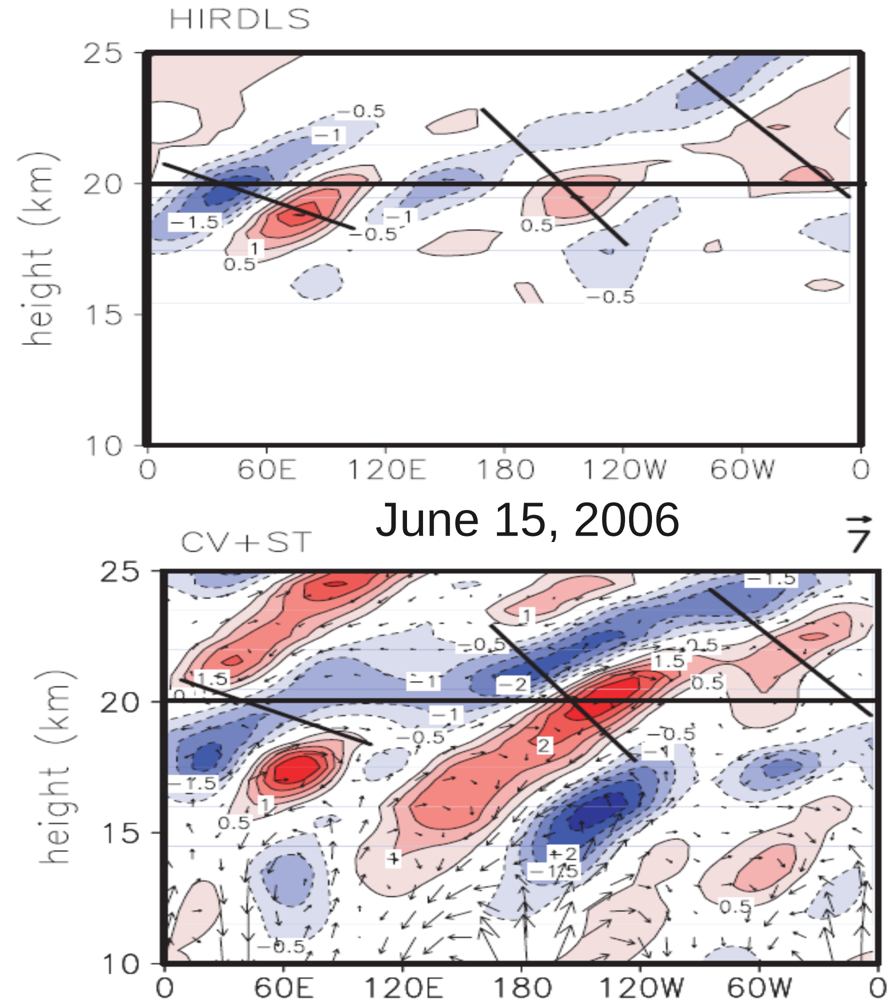
Effect is exaggerated for slow waves

Tropical Rainfall Measuring Mission (TRMM) Precipitation and Forcing of the Tropical Wave Spectrum

TRMM-based heating for May 2006



Comparison of Kelvin waves in HIRDLS observations and model (color = T' (K))



The TRMM data have 0.25° spatial and 3-hourly time resolution.

We use TRMM precipitation observations to force very realistic transient waves in a global model that can be directly validated against observations.

[Ryu et al., 2010; Alexander & Ortland, 2010]

Summary and Future Work

• HIRDLS temperatures provide unique high-resolution 3-D structure of tropical waves and their variability over three years of observations.

• Kelvin waves in the tropical tropopause layer show an annual cycle in temperature amplitude that is related to annual variations in winds and static stability. The observed amplitudes are large enough to affect cirrus formation in the upper troposphere.

• We are using the HIRDLS tropical wave observations to validate our global models of waves forced with TRMM precipitation. The model in turn allows studies of equatorial waves over the decade of TRMM measurements and their effects on circulation and transport.

References:

- Alexander, M. J. and D. A. Ortland, 2010: Equatorial waves in High Resolution Dynamics Limb Sounder (HIRDLS) data, *J. Geophys. Res.*, (accepted).

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